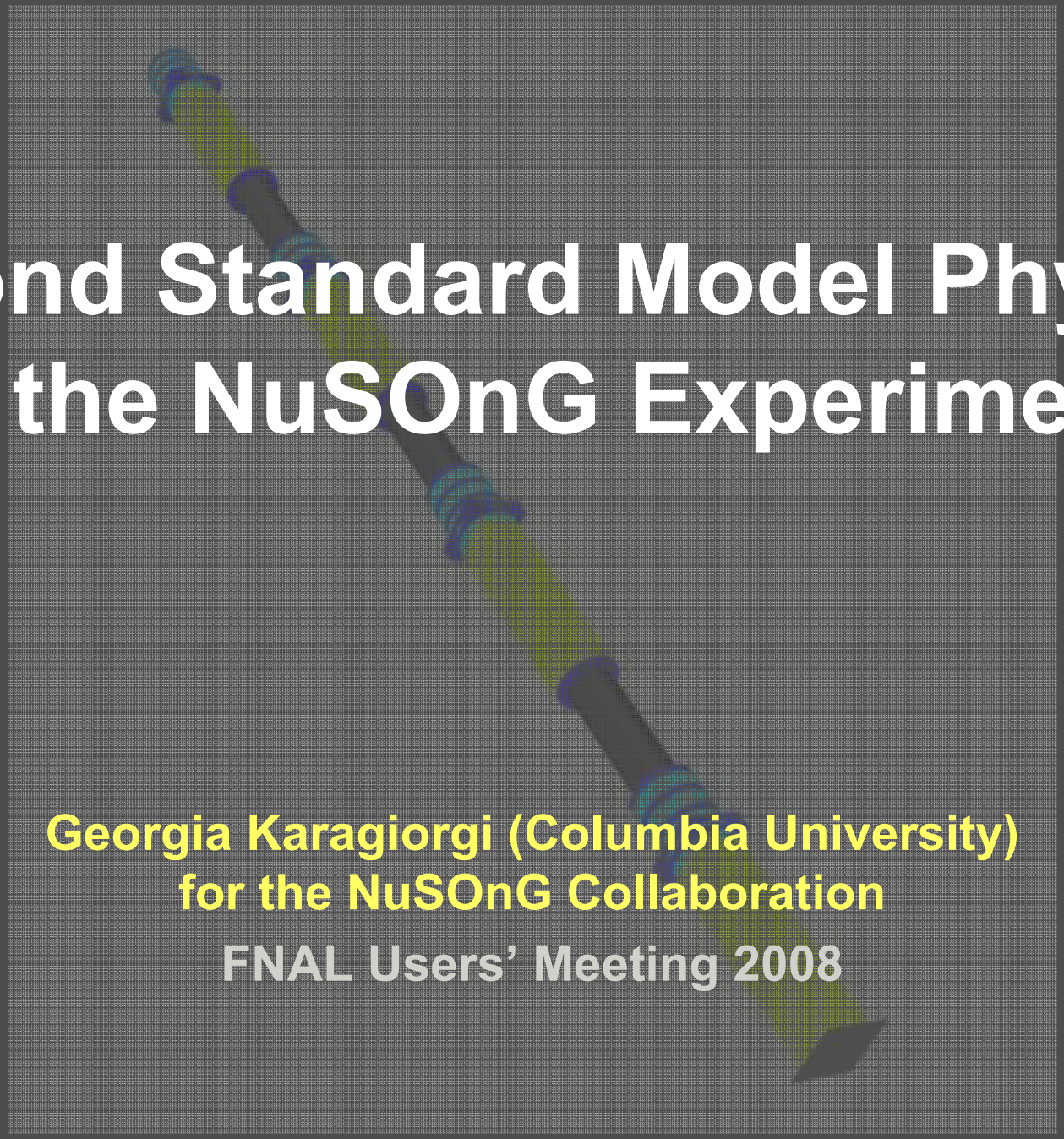
Beyond Standard Model Physics in the NuSOnG Experiment



Georgia Karagiorgi (Columbia University)
for the NuSOnG Collaboration

FNAL Users' Meeting 2008

Terascale Physics Opportunities at a High Statistics, High Energy Neutrino Scattering Experiment: NuSOnG

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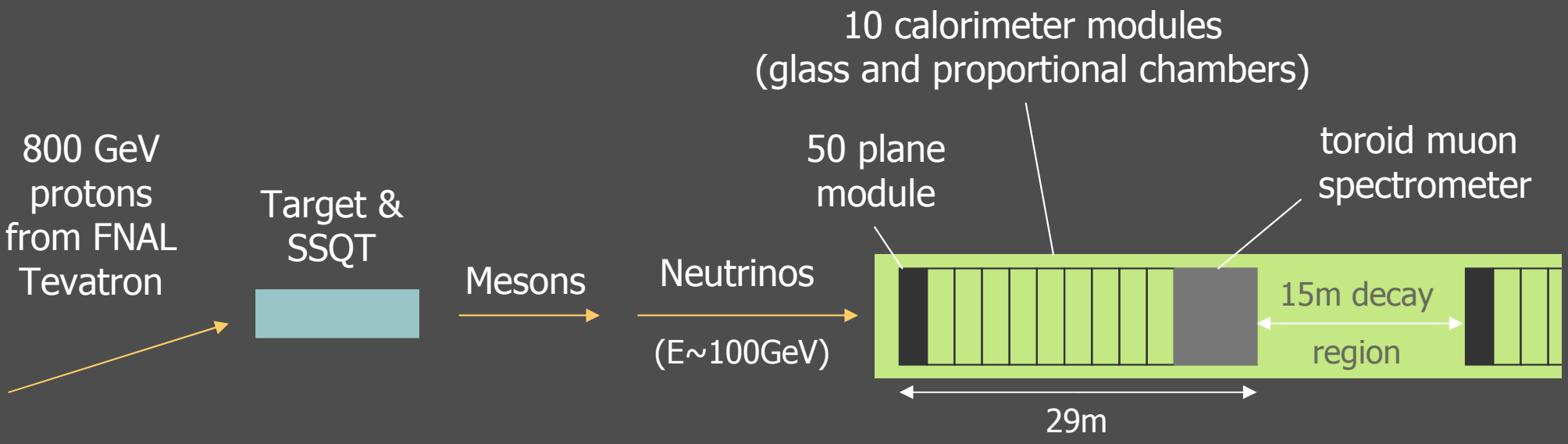
arXiv: 0803.0354 [hep-ph]

- precision measurements
- sensitivity to new physics
- complementarity to LHC (*and beyond…*)

NuSOnG can do all of the above!

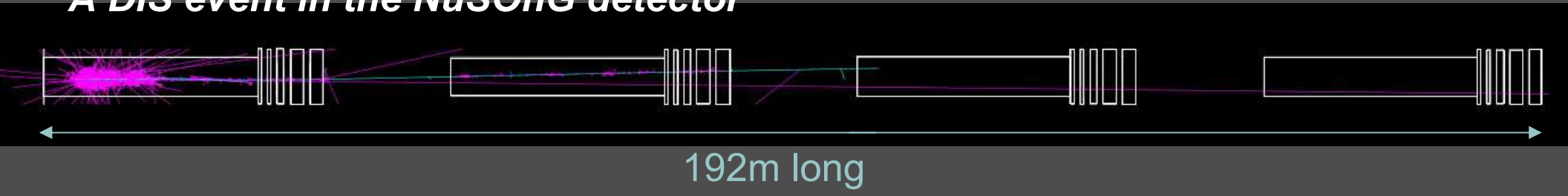
large detector



NuSOnG is a fixed target experiment

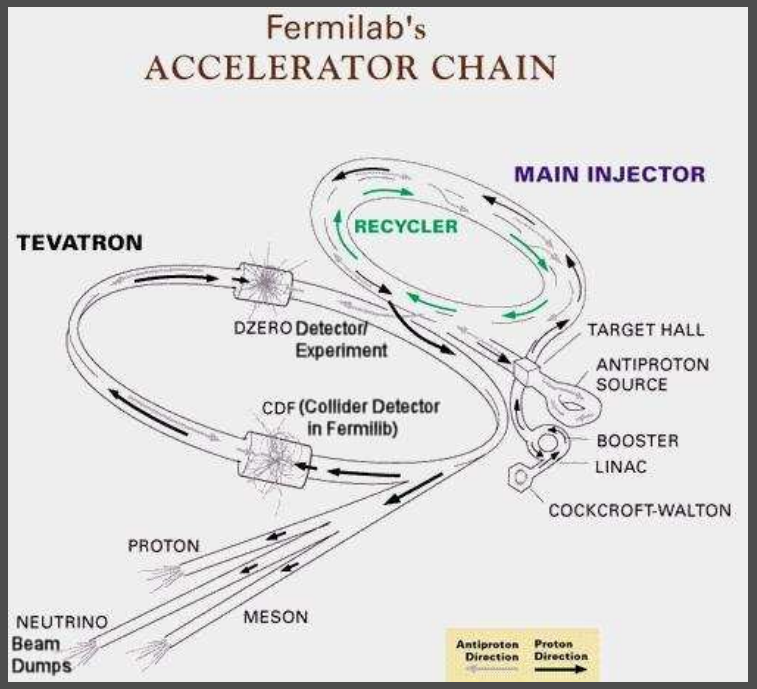
four sub-detectors in a row:
3kton total fiducial volume

A DIS event in the NuSOnG detector



a lot of protons

upgraded Tevatron beam extraction
(5 ×10^{19} protons/yr)

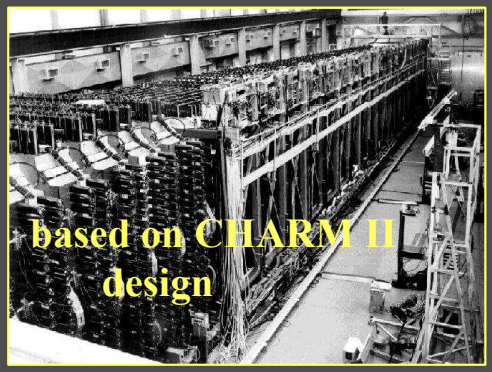


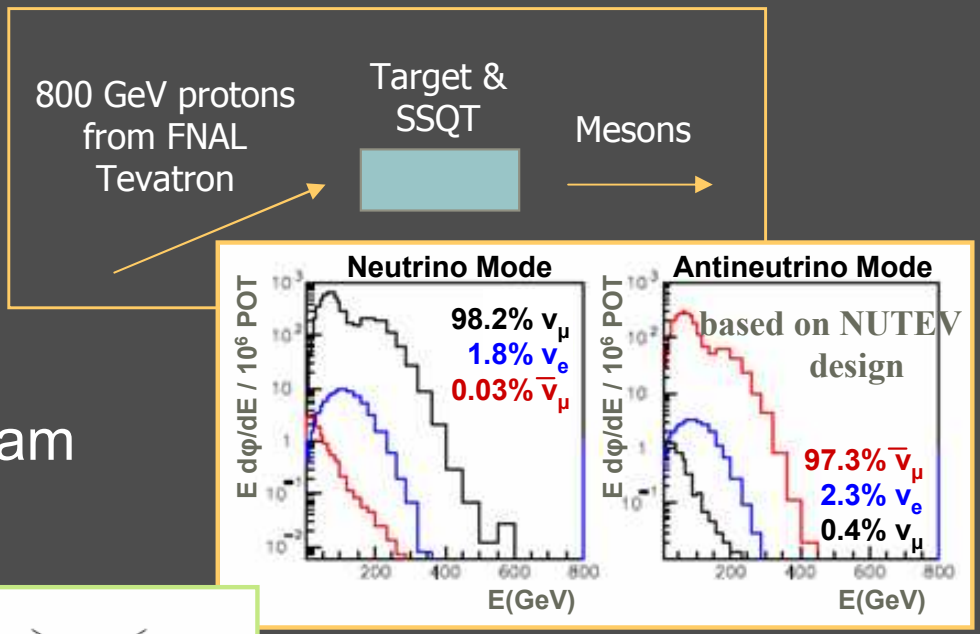
Relative to NuTeV:

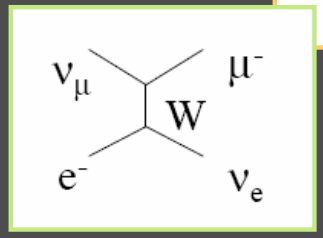
5x number of protons per fill,
1.5x faster cycle time,
66% uptime per year

low systematics

- highly-segmented detector
- isoscalar (glass) target
- beams for in situ calibration
- well-understood flux
  - sign-selected quad focused beam
  - normalization through IMD







low-E threshold at 11 GeV!

high statistics

Process	Rate	Physics	
$\nu_\mu + e^- \rightarrow \mu^- + \nu_e$ [IMD]	**700k**	**"WSIMD", non-standard interactions**	40x CHARM II
$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ [ES] **$\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$**	**75k** **7k**	**new "heavy" physics (Z', ν mixing with heavy singlets), new "light" physics, modified couplings, $\sin^2\theta_w$,** ρ, R-parity, extended Higgs	20x CHARM II
$\nu_\mu + q \rightarrow \nu_\mu + X$ [DIS] **$\bar{\nu}_\mu + q \rightarrow \bar{\nu}_\mu + X$** **$\nu_\mu + q \rightarrow \mu^- + X$** **$\bar{\nu}_\mu + q \rightarrow \mu^+ + X$**	**190M** **33M** **600M** **12M**	ν-q non-standard interactions, **$\sin^2\theta_w$,** ΔxF_3, xF_2, isospin violation	100x NuTeV
low density decay regions	***60***	**new long-lived heavy neutral particles**	30x NuTeV

Rates assume 1.5E20 POT in neutrino mode; 0.5E20 POT in antineutrino mode (5 yrs of running)

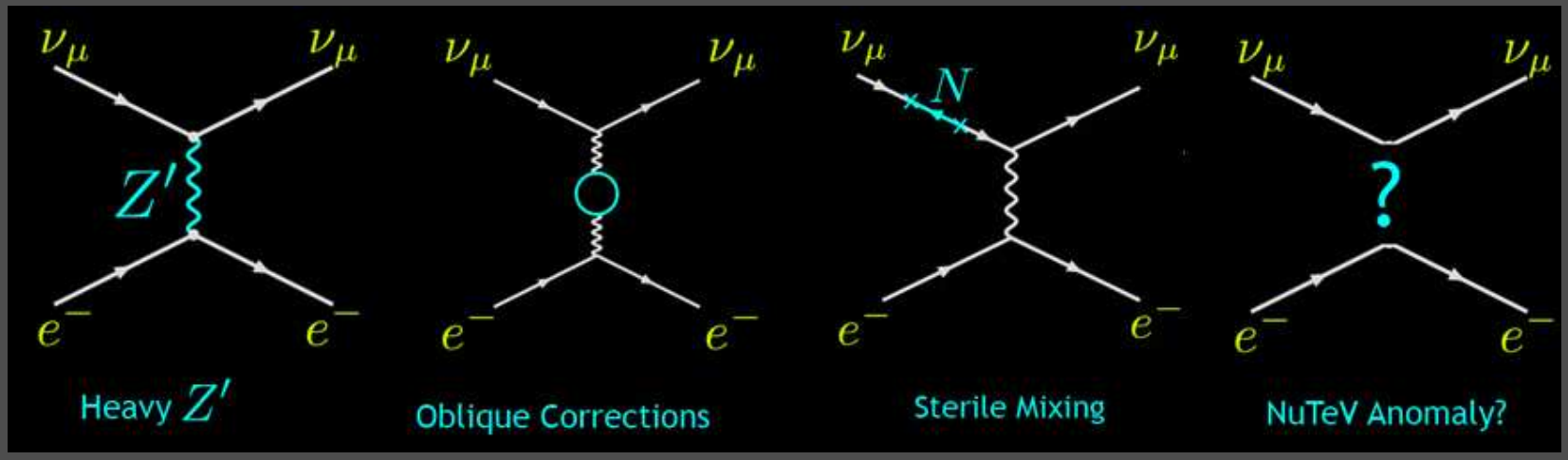
Searches for beyond-Standard-Model physics:

Indirect & Direct

by making precision measurements of SM processes to look for deviations from SM predictions

looking for low energy manifestations of beyond-SM physics

ν-e scattering: a fantastic probe for new physics at the TeV scale!

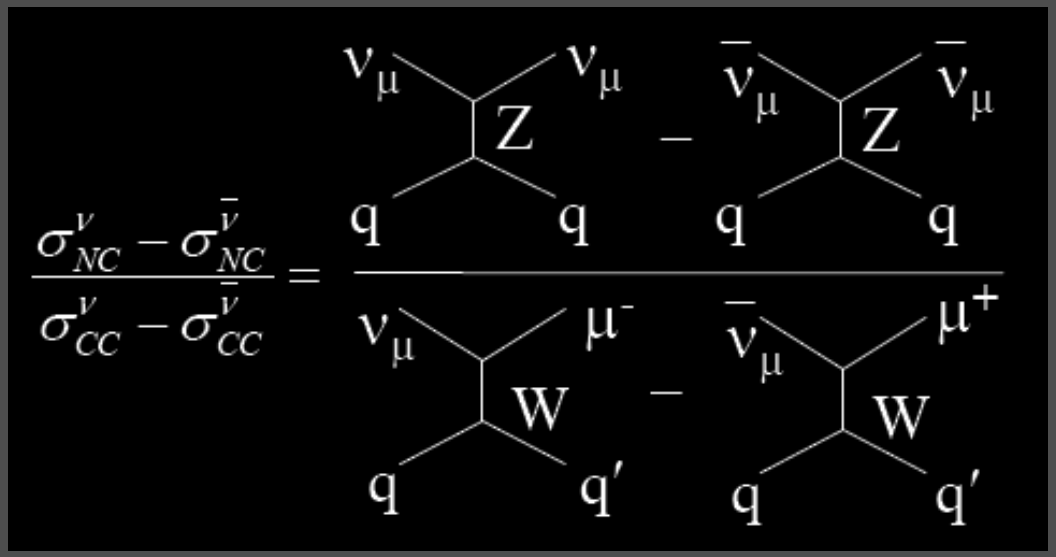


indirect searches: $\sin^2\theta_w$

Through neutrino-quark scattering, using a

Paschos-Wolfenstein style analysis ("sea" quark effects cancel)

Ratio of cross-section differences:



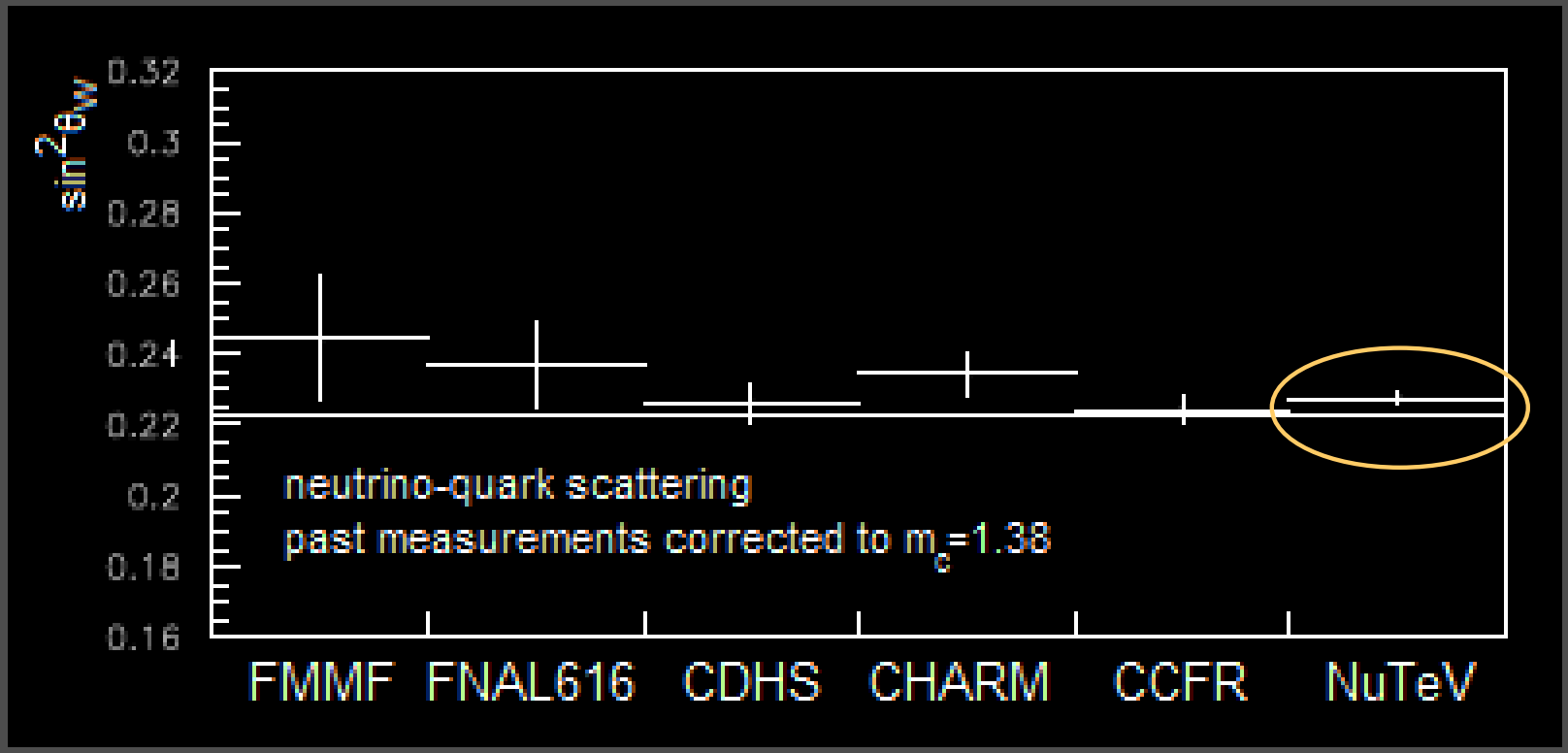
$= \rho^2 \, (1/2 - \sin^2\theta_w)$

NuSOnG expected errors: 0.4% (conservative) – 0.2% (best case)

NuTeV error: 0.7%

indirect searches: $\sin^2\theta_w$

The NuTeV anomaly: **3σ off SM prediction**



New Physics, or SM Process?

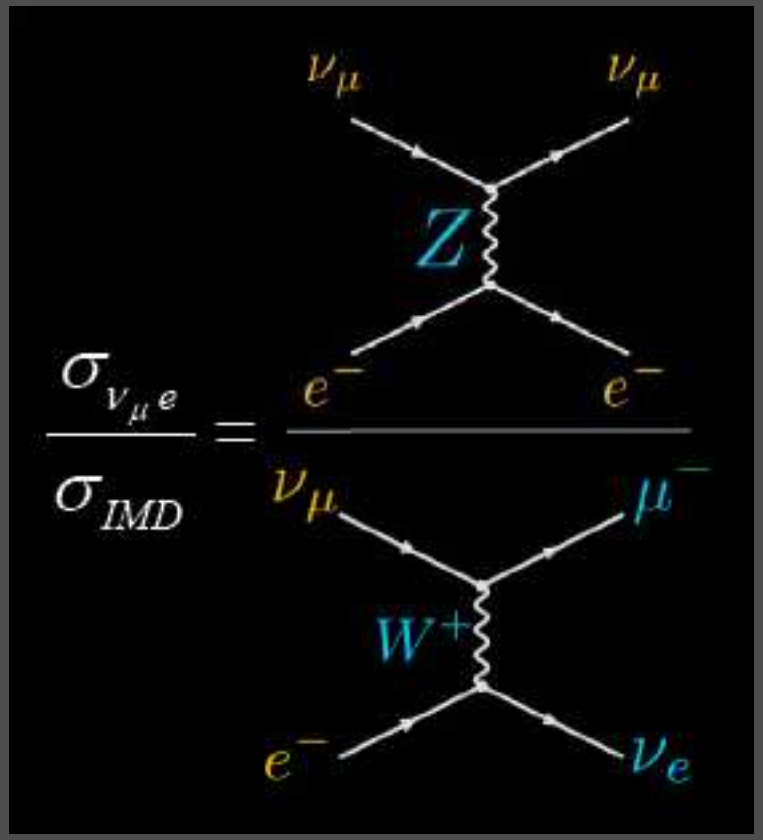
Plausible explanation: isospin violation

No isospin violation model can fully explain discrepancy!

An updated NuTeV analysis will be available this summer

indirect searches: $\sin^2\theta_w$

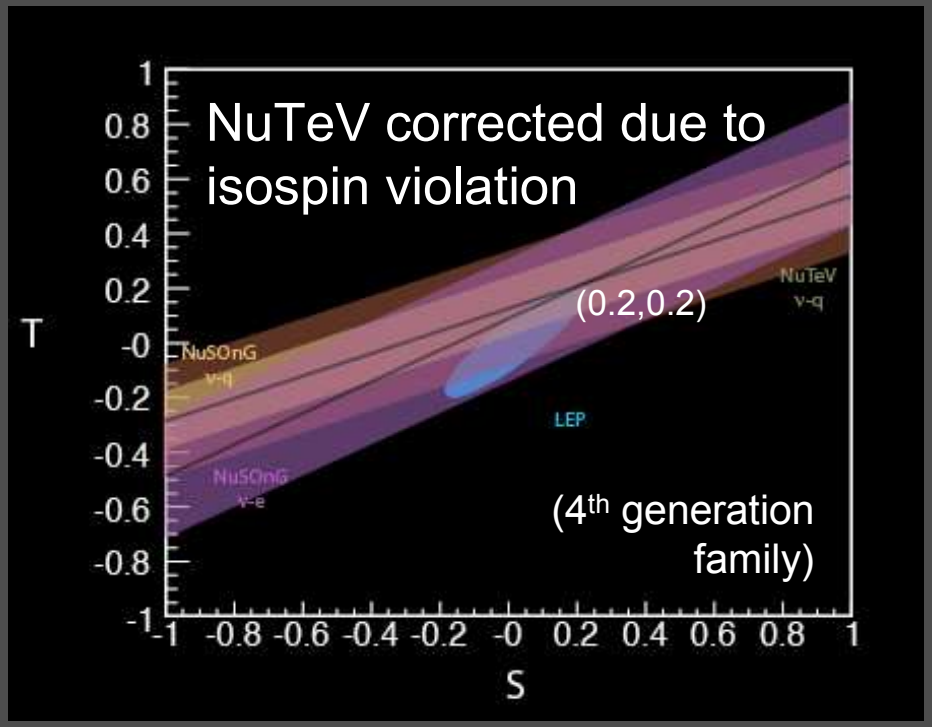
A new window: purely leptonic measurement



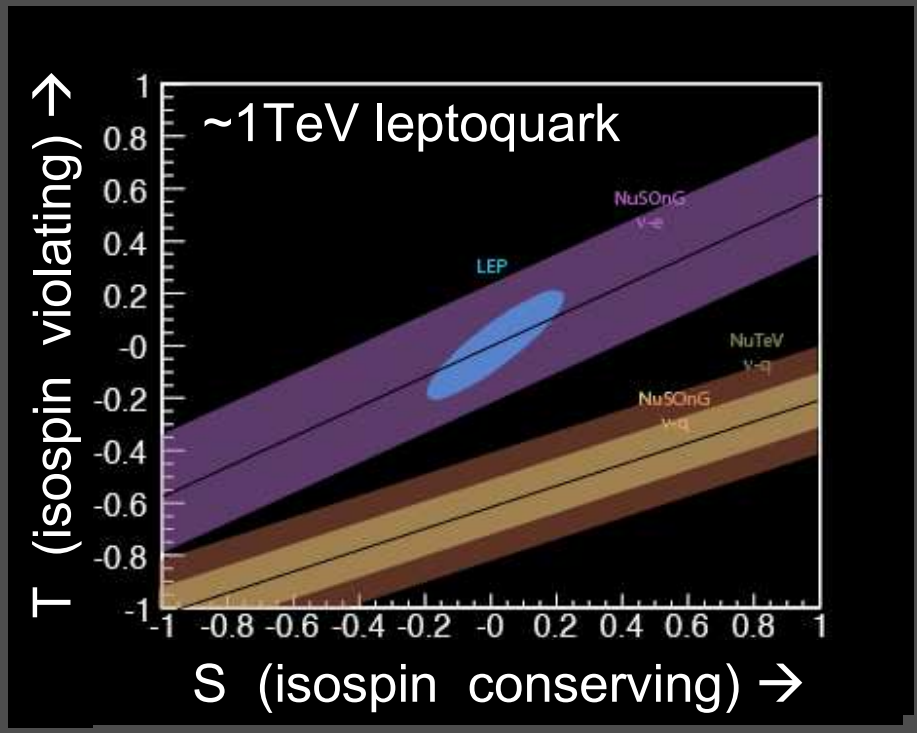
Normalizing to IMD gives sensitivity to both $\sin^2\theta_w$ and ρ!

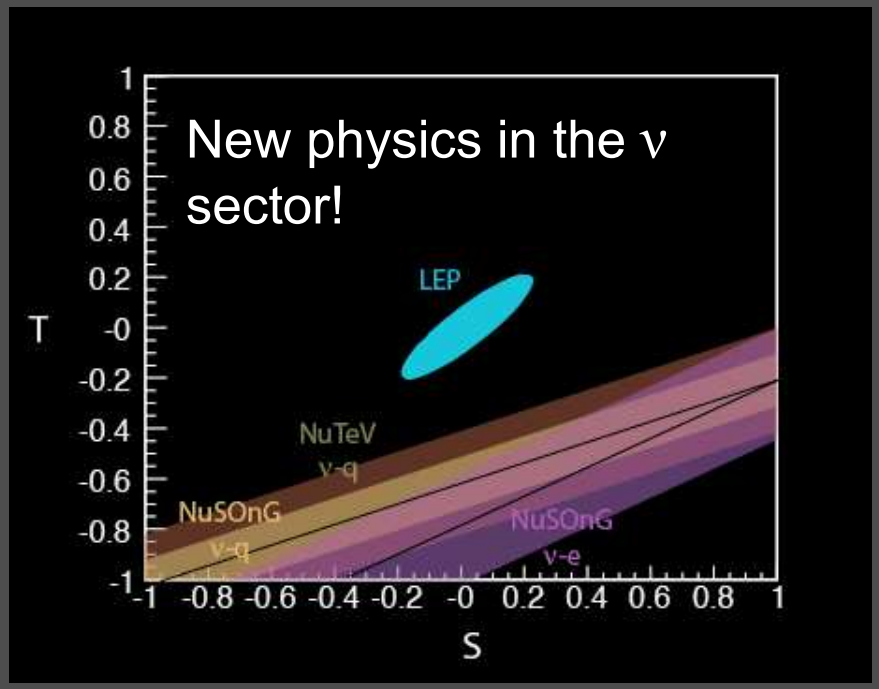
NuSOnG expected errors: 0.7% (conservative) – 0.4% (best case)
Compare to CHARM II: 3.5%

solving the puzzle



?





NuSOnG is crucial to identifying the source of possible new physics signals

indirect searches: new heavy physics

Summary of NuSOnG's contribution to Terascale physics studies:

Oblique corrections: 4 distinct probes of S and T (~25% improvement in electroweak precision)

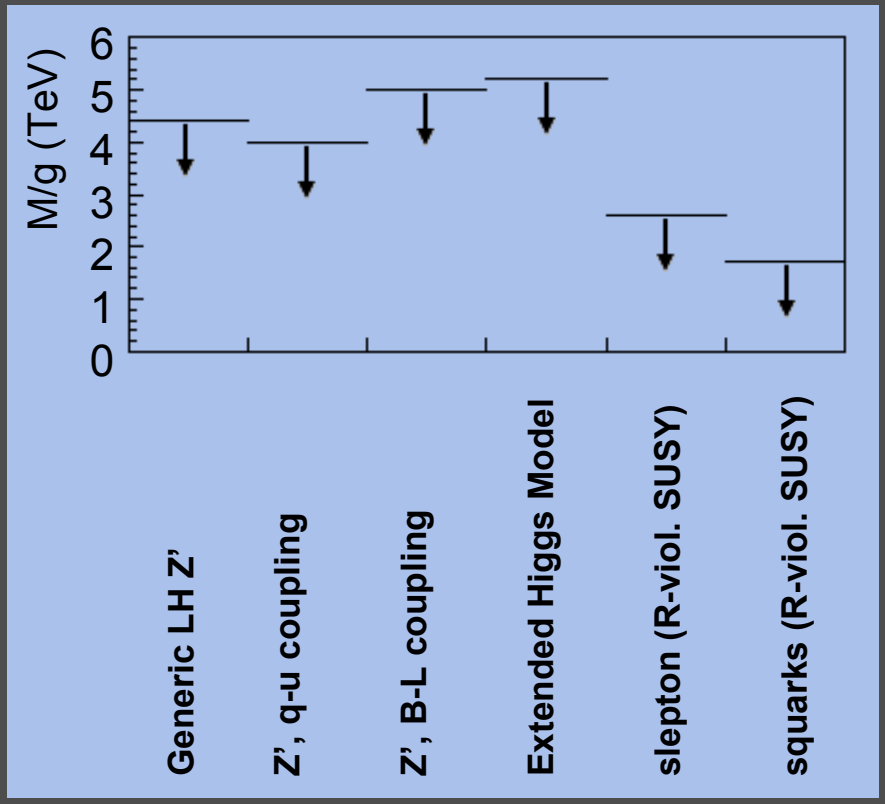
Neutrino-lepton NSIs: x10 improvement in v-e effective couplings measurements (up to 5TeV at 95%CL)

Neutrino-quark NSIs: x2 improvement in v-q effective couplings measurements (up to 7TeV at 95%CL)

Mixing with neutral-heavy leptons: ~50% improvement on μ and e family couplings

Right-handed couplings: order of magnitude improvement

NuSOnG's 2σ sensitivity for specific BSM models



direct searches: non-standard interactions

New interactions manifested through rare events

The combination of a high-intensity and high-purity beam and an instrumented detector, optimized to measure IMD with high-accuracy makes NuSOnG ideal for searching for:

Wrong Sign IMD ($\Delta L_e = -\Delta L_\mu = 2$)

$\bar{\nu}_\mu + e^- \rightarrow \mu^- + \bar{\nu}_e$ -- this is forbidden in the SM!

Best limits (90%CL) are from NuTeV
PRL 87:071803, 2001

1.7% on V-A couplings
0.6% on the scalar coupling

0.6% on V-A
0.2% on scalar

direct searches: new light physics

MIXING FREEDOM

When the 3x3 neutrino mixing matrix is *free…*

Violation of unitarity:

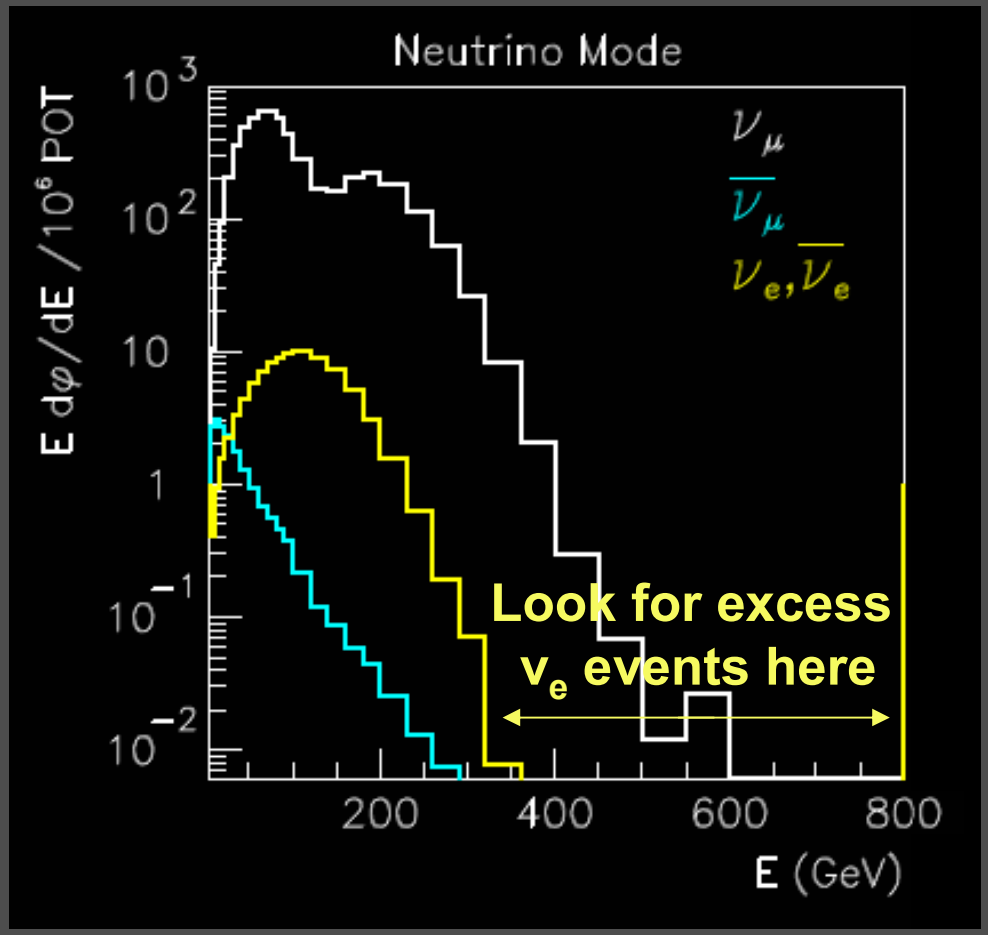
$$\sum_j |U_{\alpha j}|^2 = 1 - X_\alpha \,, \qquad U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

…striking signatures:

instantaneous (L=0) transitions from one flavor to another, or instantaneous 'disappearance'

direct searches: new light physics

MIXING FREEDOM **searches with NuSOnG**



Look for an excess of ν_e's in a range not expected

NuSOnG's reach: 10^{-5} level

direct searches: new light physics

MIXING FREEDOM **searches with NuSOnG**

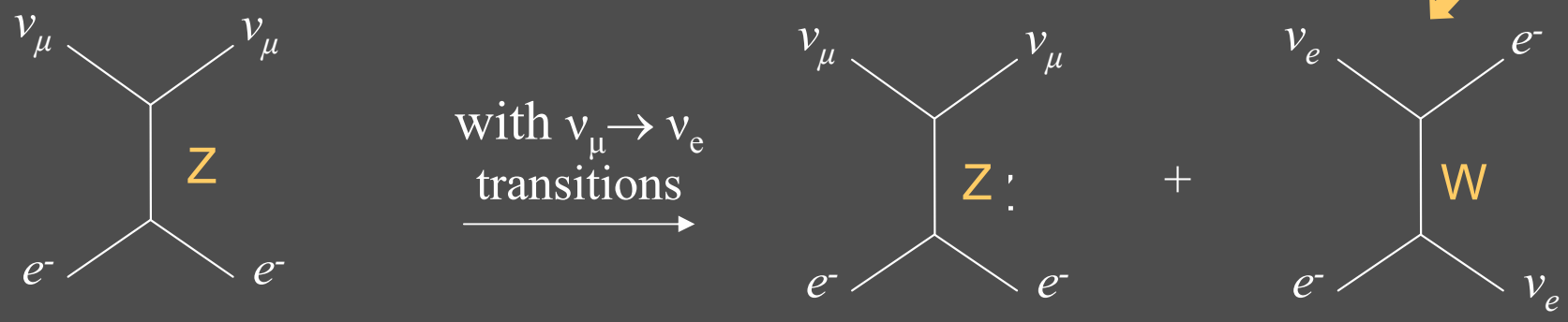
Look for "wrong sign" IMD

If $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, then $\bar{\nu}_e + e^- \rightarrow \mu^- + \bar{\nu}_\mu$

… same signature as WSIMD!

Look for increase in ν_μ- e ES scattering rate

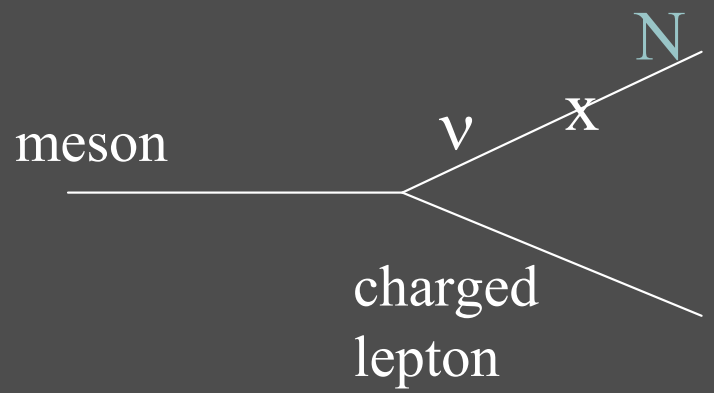
ν_e contribution from W + Z is 7x larger than Z alone

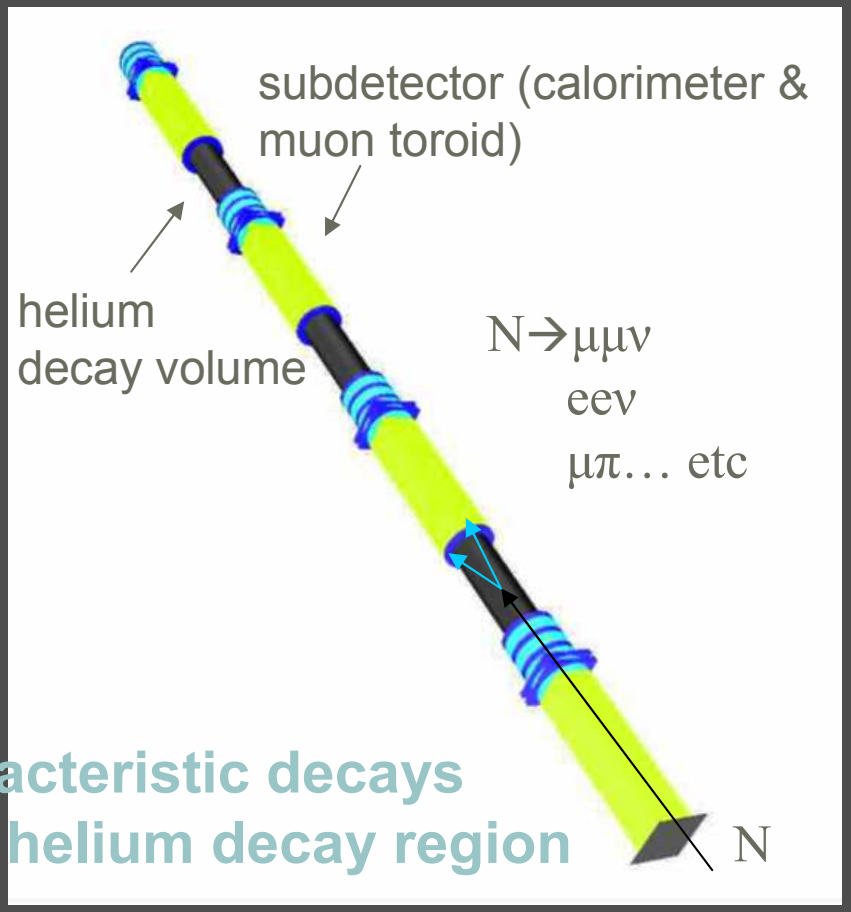


NuSOnG's reach: 10^{-3} level

direct searches: new heavy particles

neutrissimos: neutral leptons with masses 10keV – 100GeV, produced in meson decays through neutrino mixing



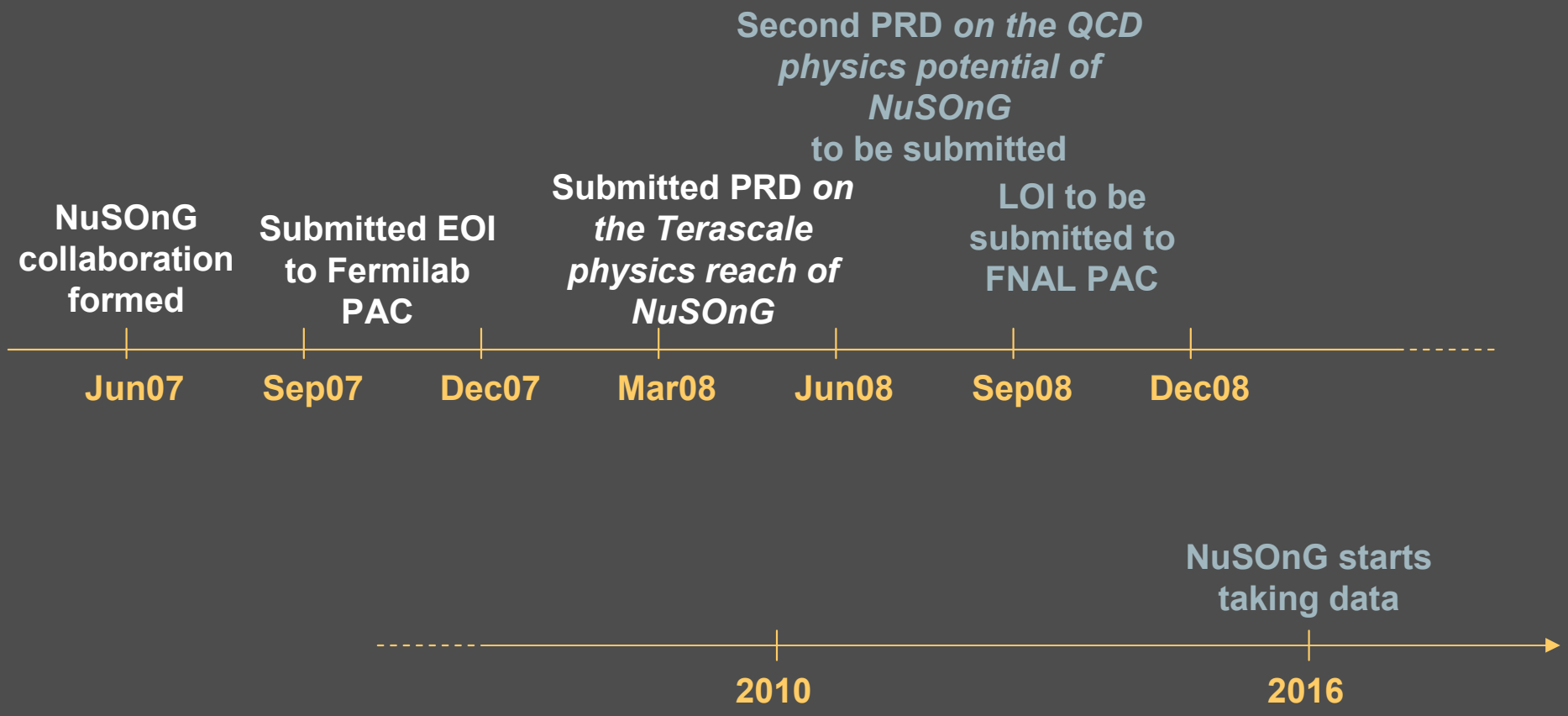


NuTeV: 3 events [arXiv:hep-ex/0009007]

Scaling up for NuSOnG:
60 signal events on a background of 2 !

Look for characteristic decays originating in helium decay region

Current status and outlook



Current status and outlook

With extended Tevatron running, which would make NuSOnG possible, there will be opportunities for a very rich Tev-based neutrino program.

Other high energy neutrino experimental possibilities:

- A small ν_τ experiment to obtain ×100 DoNuT statistics
- A large (~5kt) magnetized LAr detector for 1E6 ν_τ events
- A small dedicated search for neutral heavy leptons
- A high resolution neutrino scattering experiment to study charm and QCD ala a NOMAD type detector

These experiments can only be done at Fermilab where a high-energy, high-intensity neutrino beam is possible.

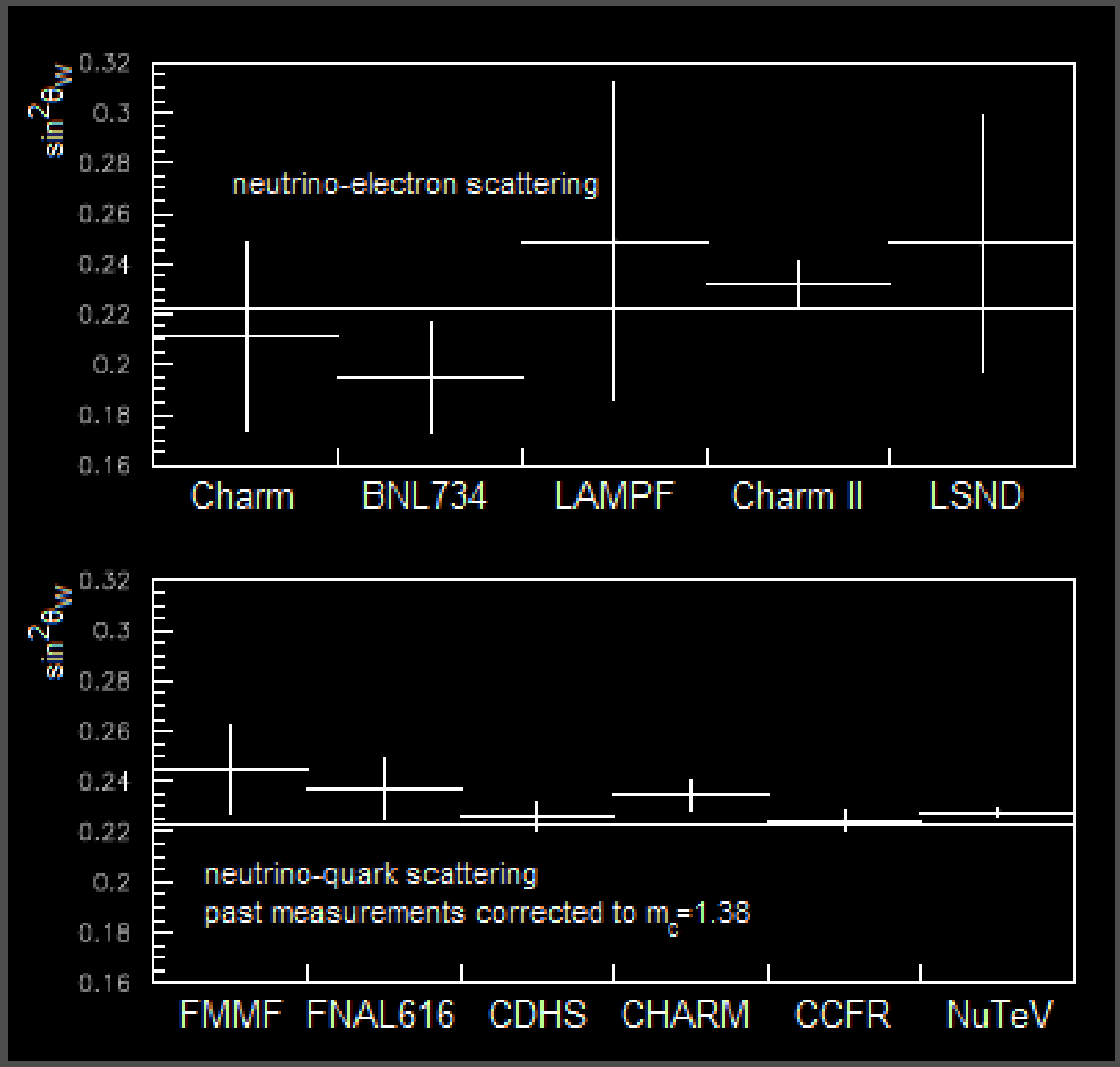
Conclusion

NuSOnG is a very exciting experiment for the future!

Backup slides

indirect searches: $\sin^2\theta_w$

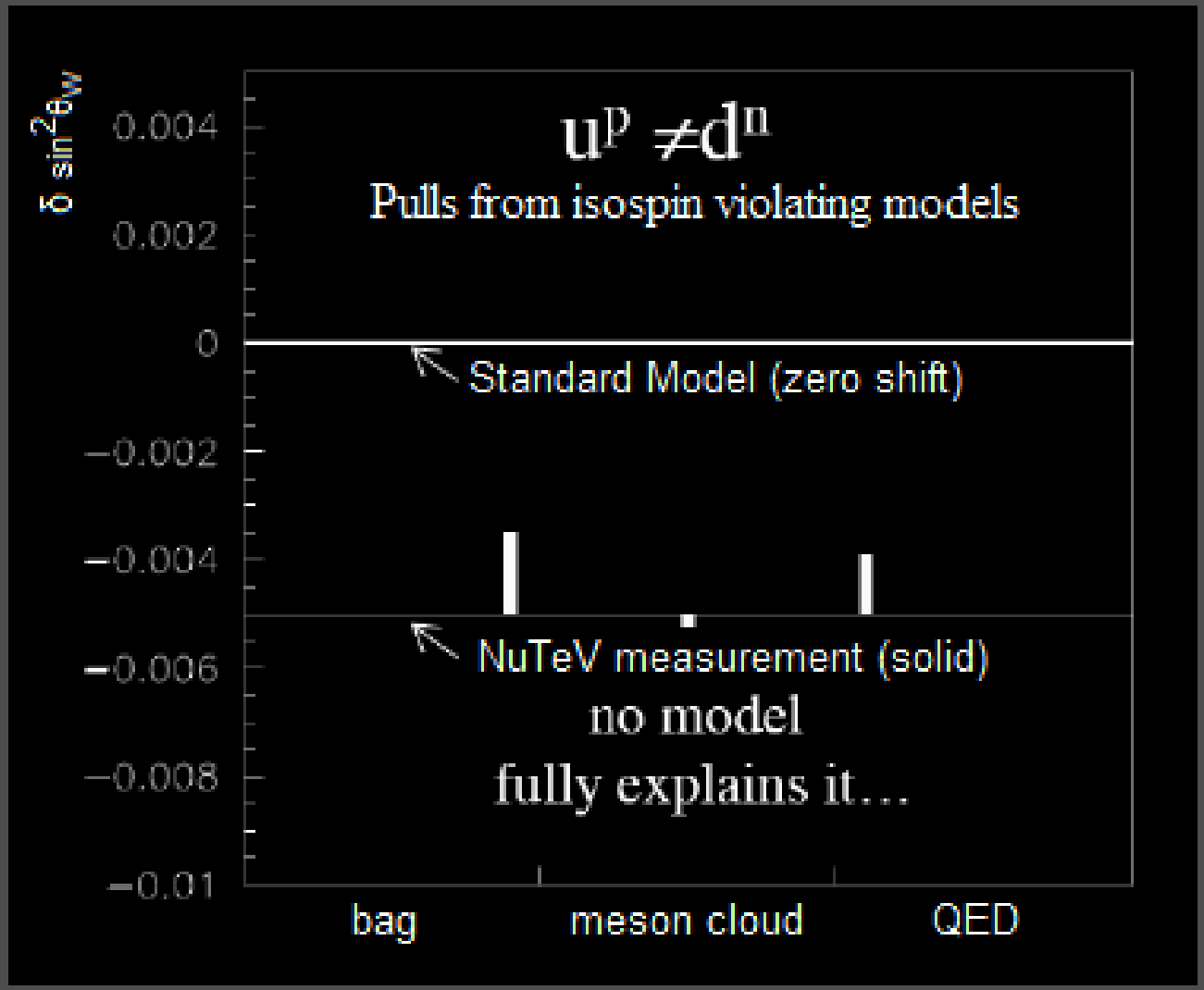
NuTeV anomaly



indirect searches: $\sin^2\theta_w$

NuTeV anomaly:

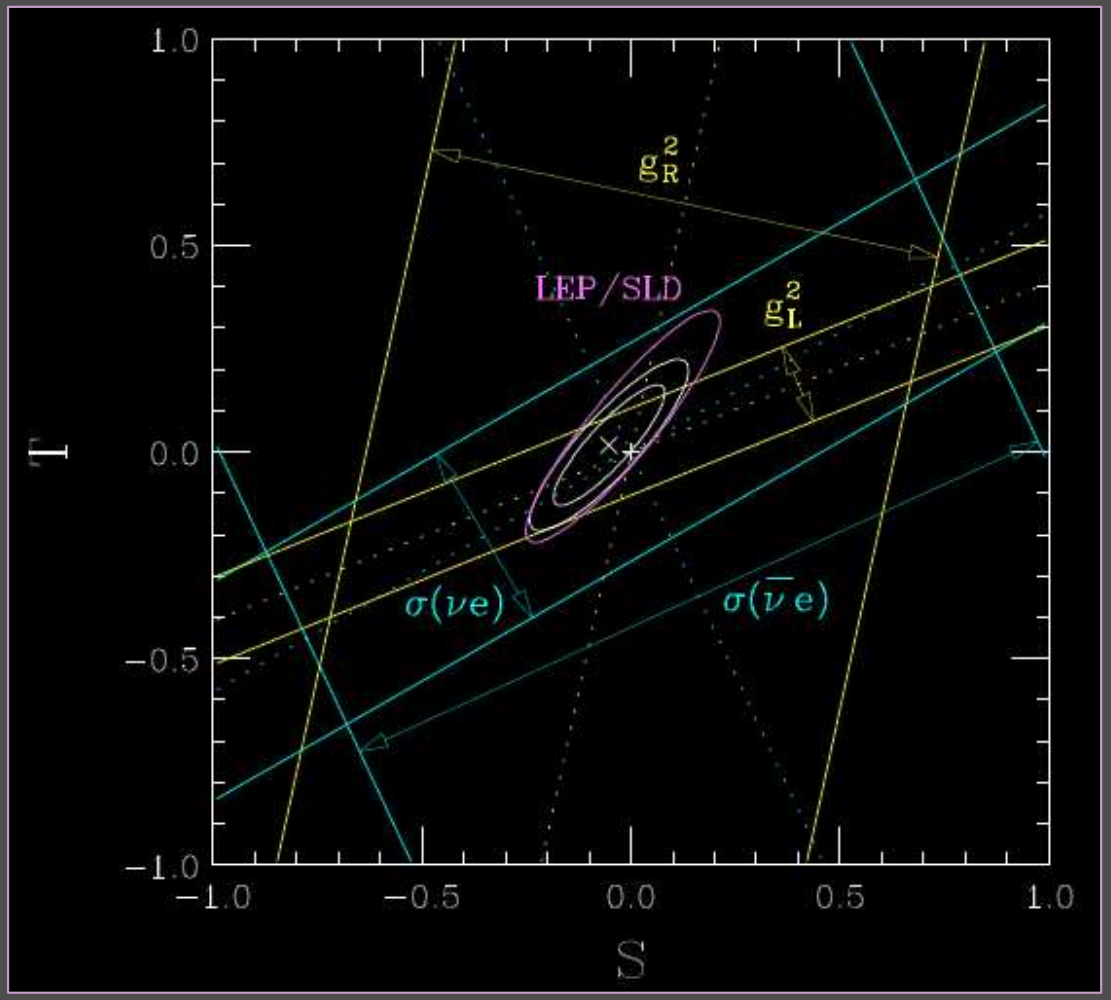
New Physics, or SM Process?



indirect searches: new heavy physics

Summary of NuSOnG's contribution to Terascale physics studies:

Oblique corrections: 4 distinct probes of S and T (~25% improvement in electroweak precision)



indirect searches: new heavy physics

Summary of NuSOnG's contribution to Terascale physics studies:

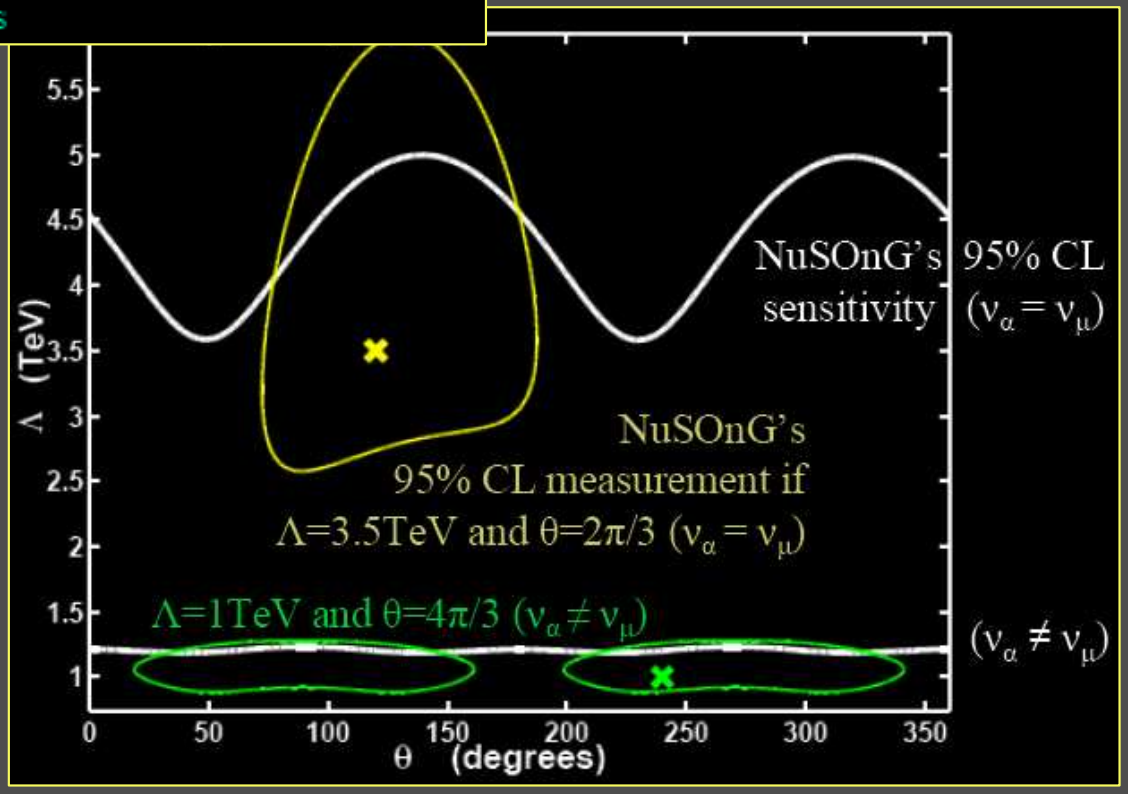
Neutrino-lepton NSIs: x10 improvement in v-e effective couplings measurements (up to 5TeV at 95%CL)

Generalized effective Lagrangian:

$$\mathcal{L}^{e}_{\mathrm{NSI}} = +\frac{\sqrt{2}}{\Lambda^2}\left[\bar{\nu}_\alpha \gamma_\sigma P_L \nu_\mu\right]\left[\cos\theta\ \bar{e}\gamma^\sigma P_L e + \sin\theta\ \bar{e}\gamma^\sigma P_R e\right]$$

Λ = New Physics Scale

θ = parameterizes "handedness" of New Physics



indirect searches: new heavy physics

Summary of NuSOnG's contribution to Terascale physics studies:

[Loinaz et al., to appear]

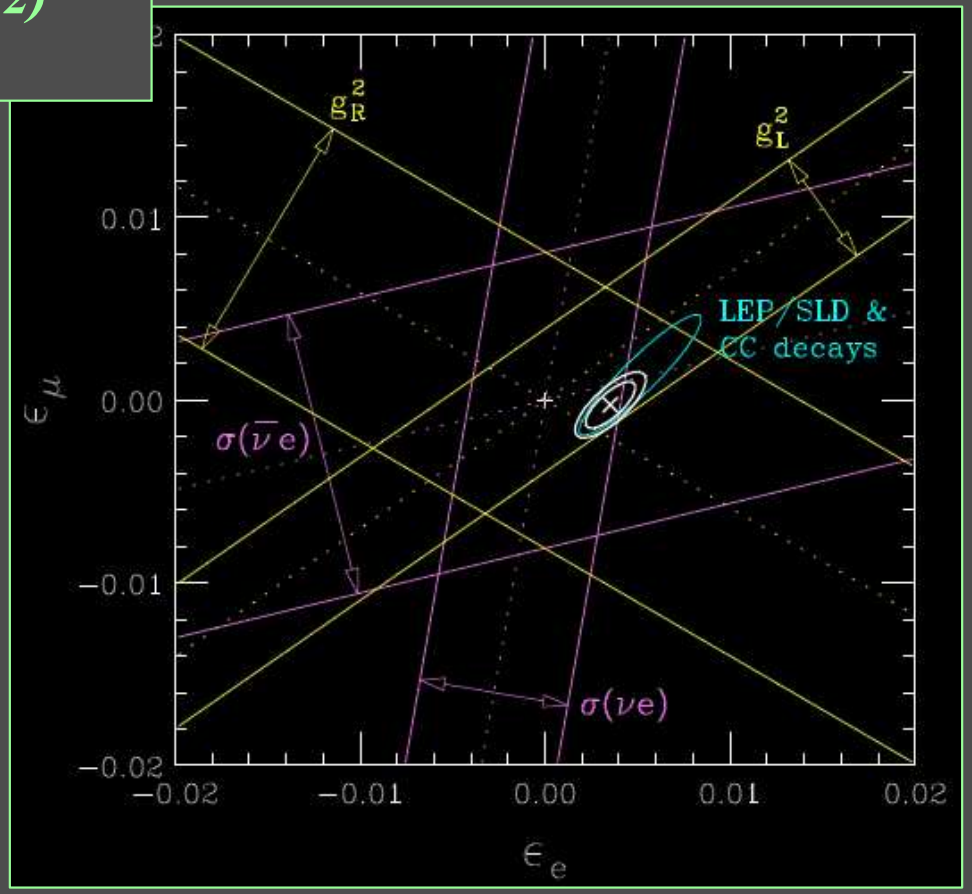
Mixing with neutral-heavy leptons: ~50% improvement on μ and e family couplings

$$\nu_{lL} = \nu_{l,light}\cos\theta_l + \nu_{l,heavy}\sin\theta_l$$

Then, the interaction of light states is given by:

$$Z\nu\nu \rightarrow Z\nu_l\nu_l(1-\varepsilon_l), \quad W\nu l \rightarrow W\nu_l l(1-\varepsilon_l/2)$$

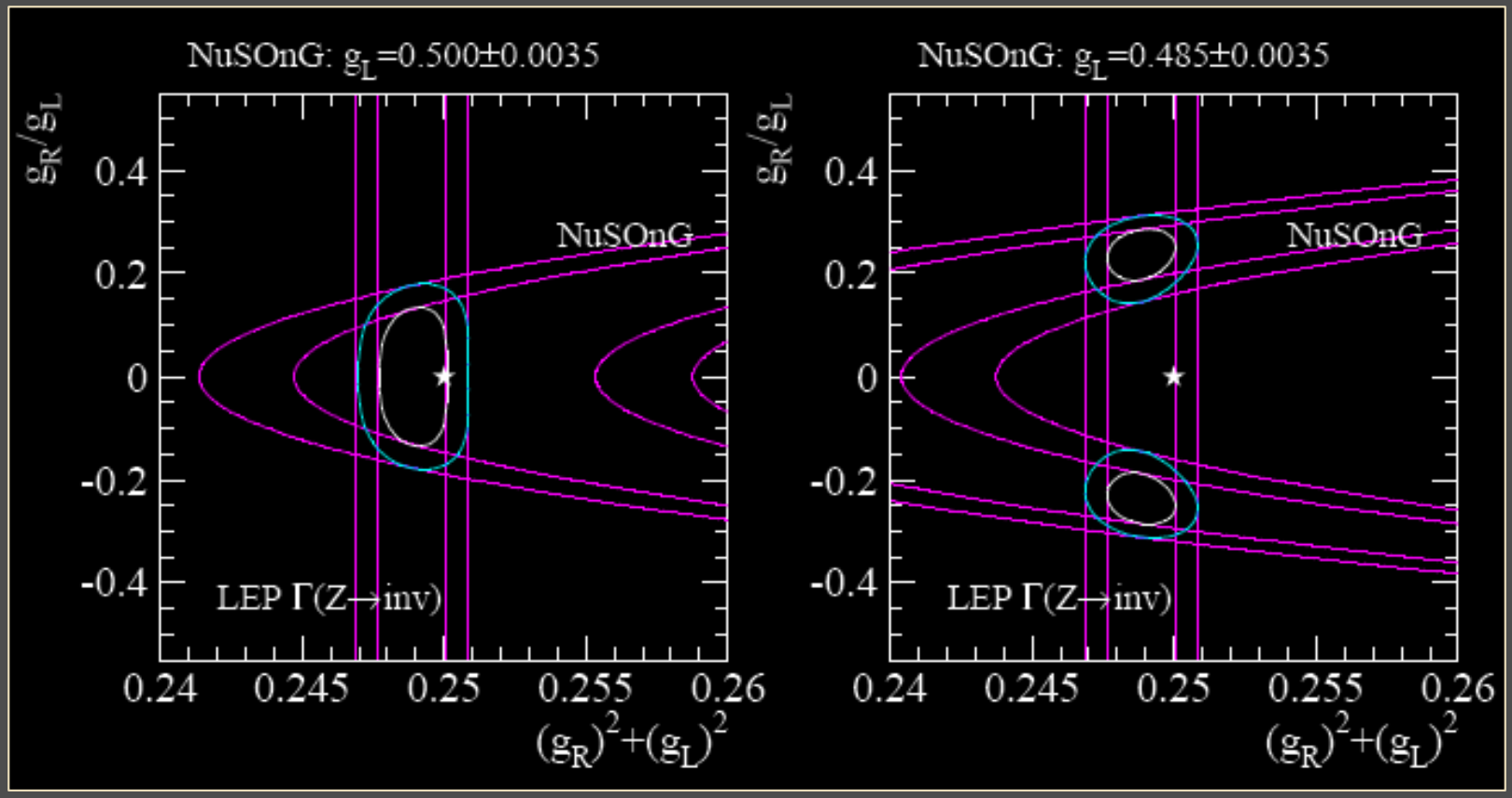
where: $\varepsilon_l = 1-\cos^2\theta_l$



indirect searches: new heavy physics

Summary of NuSOnG's contribution to Terascale physics studies:

Right-handed couplings: order of magnitude improvement



Cost Estimate:

- **Total NuSOnG with 5yrs Operations = $236M**
  - New Tevatron ν Beam: $22M
  - NuSOnG Detector Hall: $18M
  - NuSOnG Detector: $100M
  - Tevatron Operations @$15M/yr: $75M